PATENT SPECIFICATION

(11) 1 206 786

DRAWINGS ATTACHED

(21) Application No. 46240/67 (22) Filed 10 Oct. 1967
(31) Convention Application No. 79 533 (32) Filed 11 Oct. 1966 in
(33) France (FR)
(45) Complete Specification published 30 Sept. 1970
(51) International Classification H 01 h 53/08
(52) Index at acceptance
H1N 323 418 430 435 439 49X 52X 637 649 650 664 669 672 673 693 700 701 714 715 71X
H1S 95A 9AX 9C3 9D1 9D3 9D1 9D3

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(54) IMPROVEMENTS IN/OR RELATING TO ELECTRIC SWITCHES FOR HIGH CURRENTS

(71) We, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE, a French Government Administration of 15, Quai Anatole France, 75 - Paris (7ème) (France), do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

The invention relates to electric switches intended to cut off in a very short time (less than a millisecond) electric currents of very high intensity (preferably greater than a million amperes) preferably generated in electric circuits having high self impedance.

An object of the invention is to provide a switch of this type which is able to fulfill the various practical requirements better than prior-known switches, in particular with respect to the brevity of the cut-off and robustness.

The invention provides an electric switch for cutting off an electric current of very high intensity (preferably greater than a million amperes) in a very short time (less than one millisecond) comprising two conductive members electrically connected to the two terminals of the switch respectively, the members being separated from one another by a gap for containing a conductive liquid through which current will flow to establish electrical contact between the members when the switch is closed, the gap being so arranged that the liquid therein will carry current flowing in a different direction to current flowing in an adjacent conductive member so that there will be a net magnetic force tending to eject the liquid from the gap; and rapidly releasable means to maintain the liquid in the gap in spite of such force to retain the switch in its closed state, on the release of which means the magnetic force will abruptly eject the liquid partly or wholly from the gap thereby to increase the effective current path length to open the switch.

Advantageously the members together with the liquid in the gap form a generally U-shaped conductive path through which the current will flow when the switch is closed.

Preferably insulating baffles are provided in at least one of the conductive members and define a maze-like conductive path along which the current will travel after such whole or partial ejection of the conductive liquid from the gap.

Advantageously the gap which separates the two conductive members is of increasing width in the direction of the ejection of the conductive liquid the direction in which the width is measured being parallel to the direction of current flow when the switch is closed.

The invention is particularly suitable for abruptly cutting off high currents flowing in self inductances with a view to creating very intense current impulses usable in particular for the formation of plasmas.

In order that the invention may be readily understood some specific embodiments thereof will now be described by way of example only with reference to the accompanying drawings in which:—

Figure 1 is a schematic diagram of an electric circuit equipped with a switch according to the invention;

Figure 2 is a diagram showing the mode of operation of such a switch;

Figures 3 and 4 show schematically the arrangement of the conductive members in two such switches;

Figures 5 and 6 show, respectively, in axial section and in transverse section along VI-VI of Figure 5, a switch arranged according to one embodiment of the present invention in its closed state;

Figure 7 is an axial half-section of this same switch, in its open state;

[Price 5s. 0d. (25p)]

Figure 8 is an axial half-section of a modification of such a switch, also in accordance with the invention; and

Figure 9 is an axial half-section of another embodiment of a switch according to the invention.

Referring first of all to Figure 1, an electric circuit 1 has been shown having a self inductance 2 in which a current generator 3 generates a high current; a switch 4, arranged according to the present invention, is inserted in the circuit 1 to cut the high current in a very short time, in a manner, in particular, to generate a current impulse of considerable intensity.

The two terminals 5 and 6 of this switch 4 are connected respectively to two conductive members 7 and 8 separated one from the other by a small gap 9 (Figure 3). A liquid conductor 10 is introduced into this gap providing the electrical connection between the two members and means are provided for ejecting this liquid abruptly at the desired instant so as to cut this connection at that instant.

Instead of filling the gap 9 completely, the liquid conductor 10 can be in the form of a finger-like column of liquid of limited length, initially, (i.e. for the "closed" state of the switch) interconnecting the parts, of the members 7 and 8, that are adjacent the terminals 5 and 6.

During its ejection, the conductive column of liquid 10 moves progressively further away from the terminals, electrically connecting parts of these members 7 and 8 which are more and more remote from these terminals as it does so, which progressively increases the resistance between these terminals. In practice, the current cut-off is generally considered to be sufficient when this resistance reaches a value about 1000 times its initial value.

In Figure 2 each of the members 7 and 8 has been schematically represented by a series of resistances 11 and 12 of which certain corresponding points are respectively connected to conductive plates 13 and 14 insulated from one another each plate 13 being disposed opposite to a plate 14 and being able to be electrically connected to this plate 14 by the liquid finger 10. It will be easily understood from this schematic diagram that the abrupt ejection of the finger (towards the right in Figure 2) rapidly increases the total resistance of the switch by adding successive resistances between its terminals 5 and 6.

In order to eject the liquid column abruptly from its initial position, use is made of electromagnetic forces, that the electric current passing through this column exerts thereon. As is well known when two current carrying conductors extend adjacent one another there will be net forces acting on the conductors as a result of the interaction of the flux arising as a result of each current. Such forces are hereinafter referred to as "Laplace forces".

As these forces increase with an increase in the width of the finger (that is to say its dimension parallel to the direction of the current flow) and, as it is desirable to reduce the mass of liquid to be ejected as much as possible, the gap 9 may, advantageously, be of increasing width in the direction of ejection of the liquid, as illustrated schematically at 15 in Figure 4. With such arrangement the cross-section offered by the finger to the current flow remains sufficient for this finger to ensure transfer of current in the closed state of the switch without the risk of excessive heat generation in this finger, which generation would lead to vaporization of the finger and deterioration of the adjacent solid contact surfaces, and nevertheless, the mass of this finger remains small and its width quickly increases during its ejection.

Two preferred embodiments of the present invention will now be described with reference to the drawings. In these embodiments the switch is generally cylindrical in shape, and the current cut-off is obtained by the ejection of the conductive liquid radially outwardly from an annular chamber.

In the first embodiment, illustrated in Figures 5 to 7 (with an improved form shown in Figure 8), the switch comprises a central cylindrical conductive core 16 terminating in a conductive disc 17 and surrounded by an insulating sleeve 18 and conductive rings 19 axially separated from each other by annular gaps 20. Insulating rings 21 are inserted into and extend beyond the peripheral parts of the conductive rings. The core 16 and the conductive ring farthest from the terminal disc 17 are connected respectively to the two terminals 5 and 6 of the switch. This unit is mounted in a tank 22 filled partly with a conductive liquid 23 (such as mercury, sodium, potassium or another metal or alloy having a low melting point, such as the sodium-potassium eutectic or the mercury-indium eutectic), up to the level of the tops of the rings 19, and partly with a liquid 24 which is lighter and insulating, (such as water or alcohol), and which floats on the surface of the conductive liquid 23. Quick-opening valves 25 are provided in the top of the tank 22.

The operation of this switch is as follows:

Initially, the liquids 23 and 24 occupy their respective positions shown in Figures 5 and 6, the switch is closed and the electric current flows as shown by the arrows 26. The total resistance r of the system is

then small as a result of the short length of the current path and the large cross-section of the conductors.

The flow of current in the liquid exerts considerable forces (called "Laplace forces") on this liquid, which tend to eject the liquid radially outwardly from the gaps 20, but such an ejection is impossible as long as the valves 25 are closed, as the liquids are incompressible.

To cut-off the current, the valves 25 are abruptly opened. Immediately, the action of the Laplace forces results in an extremely rapid evacuation of the liquid through these gates.

It is advantageous to limit this evacuation, for example by receiving the liquid ejected through the valves in a non-deformable enclosure of limited volume, so that the conductive liquid still remains in contact with the discs 19 (Figure 7) at the end of the evacuation. The total resistance of the system will, after the liquid is ejected from the gaps, have a value of the order of 1000 *r*, for example, as a result of the increase in the current path length shown by line 27 in Figure 7, (the current following a path which circumnavigates the baffles formed by the insulating rings 21), and as a result of the decrease of the flow cross-section.

The role of the light and insulating liquid 24 is twofold: its lightness facilitates its ejection under the pressure of the heavier conductive liquid; its insulative nature prevents it closing the electric circuit directly.

The multiplicity of the conductive rings means that there is a multiplicity of annular gaps and as a result of this the unit thickness of these gaps can be reduced as can the amount of heat dissipated in each of them. Thus the proportion of the heat dissipated in the solid members is increased, and the risk of deterioration of the surfaces of these members bordering the liquid is reduced correspondingly.

It is important that all the annular gaps 20 remain filled with the conductive liquid as long as the switch remains closed, that is to say as long as the valves 25 are not open, in spite of the tendency of this liquid to move away from the bottom of these gaps under the influence of the Laplace forces.

For this purpose, it is advantageous to use the improvement shown schematically in Figure 8, wherein a longitudinal recess 28 is formed in the axial extension of the insulating sleeve 18 and communicates with the internal volume of the tank 22. This communication is established by at least one conduit 29, which extends from the axial end of the recess that is the farthest from the sleeve. The recess 28 and the conduit 29 are filled with the conductive liquid to form a reservoir.

With this arrangement, when the current flows in the switch, the hydrostatic ejection pressure exerted axially on the liquid contained in the recess 28 by the Laplace forces is greater than the pressure exerted radially on the liquid contained in the annular gaps 20. This pressure thus automatically makes up for any possible faults in filling these gaps by forcing some of the liquid from the reservoir to provide a pressure head forcing liquid into the gap, at the same time, forming a pocket 30 emptied of liquid in the recess 28 in the neighbourhood of the sleeve.

The desirability of disposing the series of rings at the exterior of the sleeve 18 rather than at the interior of the sleeve is that only in the former case (which corresponds to a radial ejection of the conductive liquid) the differences between the speeds of emptying of the various annular gaps are automatically compensated, the ejection force decreasing automatically for the gaps which empty themselves more quickly, which avoids any unbalance of an explosive type during operation of the switch.

The speed of ejection of the conductive liquid, may be regulated by ejecting it through at least one opening of a particular size which may be calibrated in an appropriate manner.

In the second embodiment schematically shown in Figure 9, the switch comprises essentially two solids of revolution adapted to be abruptly displaced axially with respect to one another, namely a first member comprising two conductive masses 31 and 32 connected respectively to the two terminals 5 and 6 and electrically insulated from one another by a disc 33 of insulating material, and a second member 34 of conductive material generally in the form of a cone housed in the interior of the first member.

In the normal position (switch closed) the second member is strongly applied against the first in the axial direction A-A for example by means of springs 35, and it is electrically connected to the first member, on the one hand by a cylindrical sleeve 36 of conductive liquid, sealed by two rings 37, retained in the mass 31, and on the other hand by two sleeves containing conductive liquid, one of these latter two sleeves 38 having the shape of a hollow truncated cone and limited by two truncated cone-shaped surfaces forming shoulders 39 and being of less sharply pointed cones than that of the sleeve 38, and the other 40 being cylindrical and on the opposite side of the sleeve 38 from the sleeve 36 and sealed by two rings 41 retained in the mass 32.

Upstream of the shoulder 39 nearest to the disc 33, that is to say on the same side of this shoulder as this disc, is a chamber 42 into which can be injected a gas under pressure through a conduit 43.

Downstream of the shoulder 39 is a duct 44 having the shape of a hollowed truncated cone which initially increases in width and which is connected to an annular collector gutter 45 by at least one conduit 46 passing through an insulating ring 47 interposed between the mass 32 and the gutter 45.

The region of the mass 32 bordering the downstream part of the duct 44 is provided with transverse baffles 48 of insulating material arranged to define a maze-like path which the current must follow when the conductive liquid is ejected from the chamber defined by shoulders 39.

The switch operates as follows:

In the closed position of the switch, the current follows the path indicated by the arrows 51, which is short and has a large flow cross-section, by crossing successively the two liquid sleeves 36 and 38.

In order to cut-off this current, a mass 49 is projected axially against the member 34. Under the effect of the shock, the member 34 moves towards the right.

Immediately, the shoulders 39 separate and the Laplace forces, preferably aided by the compressed gas introduced into the chamber 42, eject the liquid of the sleeve 38 towards the duct 44 and the gutter 45. During such ejection finger 50 of this liquid is formed which finger becomes progressively smaller in size in the direction of its ejection and greater in size in the direction of the current flow as the width of the duct 44 increases.

The enormous quantity of heat then applied to this finger partially or totally vapourises the finger and brings it in a very small fraction of a second to a high temperature. At this temperature the latent heat of vaporisation or the latent heat of ionization of the finger it very high so that, in spite of its small mass, it can absorb large calorific energies due to the successive electric commutation of the different layers of the mass 32, separated by the baffles 48.

The high disruptive force which appears just upstream of the finger 50 is contained by the pressure of the gas injected at 42. In order that this gas can fulfill this role and follow the finger, it is desirable that it is light, difficult to ionize, highly compressed and, possibly, preheated. For example, this gas can be constituted by hydrogen or helium at 1000-1500°C and compressed at 100 or 200 kg/cm^2.

After the ejection of the finger, the current is obliged to follow the path indicated by the arrows 52, this path being long and of small flow cross-section. The increase in resistance is such that the switch can then be considered to be open.

To re-set the device, it is sufficient to again apply the piece 34 against the piece 32 and to re-inject some conductive liquid into the sleeve 38.

As a result, which ever embodiment is adopted, a switch is provided which cuts off in a very small fraction of a second (that is to say less than one millisecond, and sometimes as low as 10 microseconds or even less) a very intense electric current (for example of intensity greater than 1 million amperes) such as for example those generated by the dynamos described in British Patent No. 1,042,451 filed by the present applicants on March 19, 1963 and entitled "Improvements in machines and methods for producing high intensity electric currents".

Such a switch can be used for many purposes, for example to make a large fraction of the energy stored in the self inductance 2 of Figure 1 pass abruptly into a self inductance 53 (Figure 1) mounted in parallel with the switch. This is especially advantageous when creating the intense electric current envisaged in the previous paragraph, the magnetic field then generated in the self inductance 53 being much greater than that generated in the self inductance 2.

Various modifications of the embodiments described above are possible, such as a modification in which the progressive increase of the circuit resistance caused by the finger is obtained, not by the successive addition of resistances mounted in series, but by the discontinuous modification of resistances arranged in parallel. In this case the finger comes, for example, successively into contact with parallel plates whose ends facing the finger are insulated from one another whereas their other ends are interconnected, these plates being of different thicknesses and/or natures.

WHAT WE CLAIM IS:—

1. An electric switch for cutting-off an electric current of very high intensity in a very short time comprising two conductive members electrically connected to the two terminals of the switch respectively, the members being separated from one another by a gap for containing a conductive liquid through which current will flow to establish electrical contact between the members when the switch is closed, the gap being so arranged that the liquid therein will carry current flowing in a different direction to the current flowing in an adjacent conductive member so that there will be a net magnetic force tending to eject the liquid from the gap; and rapidly releasable means to maintain the liquid in the gap in spite of such force, to retain the switch in its

closed state, on the release of which means the magnetic force will abruptly eject the liquid partly or wholly from the gap thereby to increase the effective current path length to open the switch.

2. An electric switch as claimed in claim 1, wherein the members together with the liquid in the gap form a generally U-shaped conductive path through which the current will flow when the switch is closed.

3. An electric switch as claimed in claim 1 or claim 2, wherein insulating baffles are provided in at least one of the conductive members and define a maze-like conductive path along which the current will travel after such whole or partial ejection of the conductive liquid from the gap.

4. An electric switch according to any one of claims 1 to 3, which is of generally circular cross-section, the gap forming an annular chamber from which the conductive liquid is wholly or partly ejected in a radial direction to cut-off the current.

5. An electric switch according to claim 4, wherein the adjacent conductive member extends axially of the annular chamber.

6. An electric switch according to claim 5, wherein the conductive members are separated by a series of such annular chambers formed by parallel conductive rings mounted on an axially extending insulating sleeve itself surrounding the adjacent conductive member which forms a core, one end of which core is electrically connected to one of the conductive rings, each conductive ring carrying an insulating ring which projects beyond its periphery to prevent conductive liquid associated with adjacent chambers from coming into electrical contact, the rapidly releasable means comprising an insulating liquid filling a tank in which said conductive rings, chambers and baffles are located from which tank the insulating liquid can abruptly be released to flow into a second tank to permit said ejection of the conductive liquid from the annular chambers.

7. An electric switch according to claim 6, wherein a reservoir for conductive liquid is provided adjacent the said one end which reservoir extends in an axial direction substantially in line with a portion of the sleeve, there being at least one duct extending from an end of the reservoir remote from the sleeve to the liquid in the tank, the liquid in the reservoir providing a path for current flowing from the core to the conductive ring.

8. An electric switch according to any one of claims 1 to 3, wherein the gap comprises an enclosed chamber defined by adjacent truncated-cone shaped surfaces formed on each member, and the two members are mounted for movement relative to one another so that they can be abruptly separated one from the other in a direction parallel to the axis of the gap to open the chamber and to allow the conductive liquid to be ejected from the gap during cut-off.

9. An electric switch according to any one of claims 1 to 3, or claim 8, comprising means to apply a compressed, non-conductive fluid to said gap to aid the ejection of the liquid therefrom by the magnetic forces.

10. An electric switch according to any one of claims 1 to 3 or claim 8 or claim 9 wherein the gap which separates the two conductive members is of increasing width in the direction of the ejection of the conductive liquid, the direction in which the width is measured being parallel to the direction of current flow when the switch is closed.

11. An electric switch according to claim 3 or any one of claims 8 to 10, wherein the baffles of electrically insulating material are provided in a region of at least one of the conductive members which delimits a downstream region of the gap (with respect to the direction of ejection of the liquid) which separates these two pieces.

12. An electric switch substantially as hereinbefore described with reference to and as illustrated in Figures 5, 6 and 7, of the accompanying drawings.

13. An electric switch substantially as hereinbefore described with reference to and as illustrated in Figure 8 of the accompanying drawings.

14. An electric switch substantially as hereinbefore described with reference to and as illustrated in Figure 9 of the accompanying drawings.

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Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1970
Published at the Patent Office. 25 Southampton Buildings, London WC2A 1AY from which copies may be obtained.

Fig. 1.

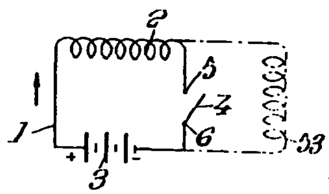


Fig. 2.

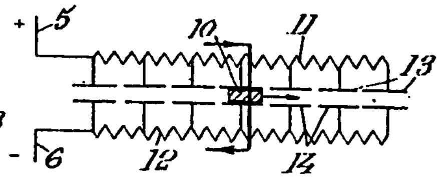


Fig. 3.

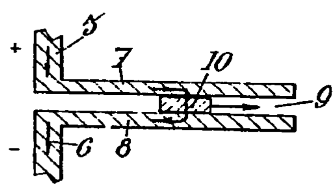


Fig. 4.

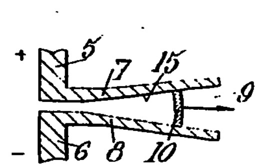


Fig. 5.

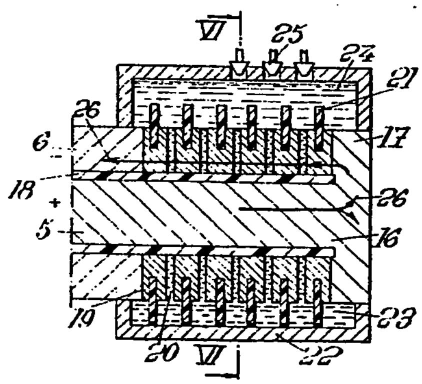
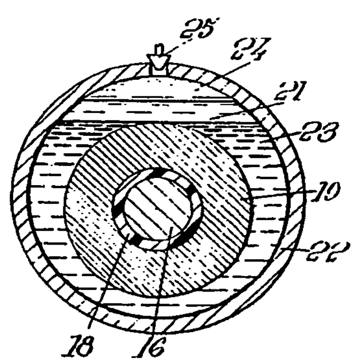


Fig. 6.



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Sheet 2

Fig. 7.

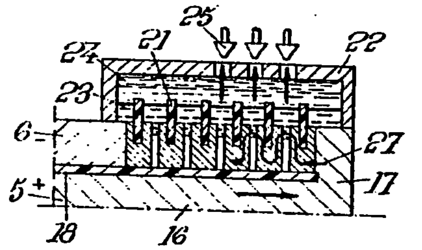

Fig. 8.

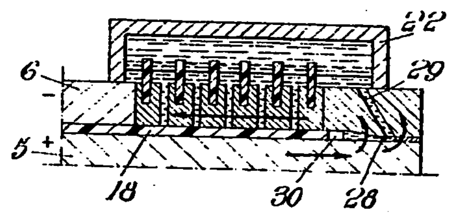

Fig. 9.